

METHOD FOR CONTROLLING THE VALVE LIFT OF DISCRETELY
ADJUSTABLE INLET VALVES IN A MULTI-CYLINDER INTERNAL
COMBUSTION ENGINE

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CLAIM FOR PRIORITY

This application claims priority to German Application No. 10231143.9, which was filed in the German language on July 10, 2002.

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TECHNICAL FIELD OF THE INVENTION

The present invention relates to a method for controlling the valve lift of discretely adjustable inlet valves in a multi-cylinder internal combustion engine, the operation of which is regulated by an electrical operation control 15 unit.

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BACKGROUND OF THE INVENTION

Internal combustion engines with inlet valves, the valve lift of which can be adjusted between a low and high 20 value, in other words discretely, for example using an adjustment mechanism, are increasingly being used in motor vehicles, for example see DE 195 20 117 and MTZ Motortechnische Zeitschrift 61 (2000), 11, p. 730 - 743. On switching over the valve lift, the air mass in the 25 cylinders as well as the volume of injected fuel undergo a sudden change, which causes a correspondingly sudden change in the torque, unless the torque is suppressed via a regulating operation. An option for suppressing these sudden changes in torque is by operating the cylinders at 30 a reduced level of efficiency, for instance by adjusting the ignition angle, directly after a valve lift switchover, for example from a lower to a higher value, thus decreasing the excess torque that is created when the valve lift switches over. However, such a switchover 35 strategy would be at the expense of increased fuel consumption.

SUMMARY OF THE INVENTION

In one embodiment of the present invention, there is a method for controlling the valve lift of discretely adjustable inlet valves in a multi-cylinder internal 5 combustion engine, permitting a valve lift switchover which consumes as little fuel as possible at a torque which is as regular as possible.

10 In one aspect according to the invention, the valve lift is firstly adjusted for a section of cylinders, while the remaining section of cylinders is adjusted after a delay.

15 In doing so, it is possible for the valve lift to be adjusted for each individual cylinder or in groups of cylinders in succession. However, it is preferable for the valve lift to be adjusted firstly for half the cylinders and then for the other half. In each case, it is important to note that the valve lift for the first section of cylinders is adjusted in such a way that 20 combustion in each cylinder in the first section of cylinders takes place alternately with combustion in a cylinder in the second section of cylinders.

25 By switching the valve lift over in stages as proposed according to the invention, only a small change in torque occurs each time during the switchover processes, which can be compensated with greater ease and more efficient consumption via a corresponding regulating control operation. The respective change in torque which would 30 arise if no regulating control operation took place during the switchover processes is expediently compensated by changing the efficiency of at least some of the cylinders. The change in efficiency is preferably achieved by changing the ignition angle for the cylinders 35 in question. Another option for compensating the change in torque is to change the air/fuel ratio. It is also possible to combine both options.

When the valve lift is adjusted for the first section of cylinders, the throttle valve mounted in the intake tract of the internal combustion engine is expediently adjusted in such that the pressure in the intake tract moves 5 toward a target value, at which all cylinders operate again at optimum efficiency once the valve lift has been switched over.

Once the valve lift has been adjusted for the first 10 section of cylinders, the regulating control by the electronic operation control unit ensures that the cylinders return to operating at optimum efficiency, e.g. with a base ignition angle and/or an air/fuel ratio of one. The valve lift for the second section of cylinders 15 is to be adjusted at this point at the latest.

If the change in torque occurring with a valve lift adjustment without any additional regulating control operation is compensated by adjusting the ignition angle, 20 the case may arise under specific operating conditions in which the ignition angle adjustment required to avoid a sudden change in torque is so large that the minimum ignition angle would have to be undershot. However, as the regulating control by the operation control unit 25 restricts the ignition angle to the minimum ignition angle, a sudden change in torque would nevertheless occur in this case.

According to another aspect of the present invention, a 30 criterion is specified for the option of switching valve lift over at neutral torque. If this criterion shows that it is not possible to switch valve lift over at neutral torque with a required valve lift switchover, there will either be no valve lift switchover at this point or a 35 valve lift adjustment will take place for a reduced number of cylinders.

BRIEF DESCRIPTION OF THE DRAWINGS

Further details according to the invention are described in connection with the drawings, in which:

5 Figure 1 shows an internal combustion engine.

Figure 2 shows a flow diagram illustrating an example of a method according to the invention to control the valve lift of inlet valves.

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DETAILED DESCRIPTION OF THE INVENTION

Figure 1 shows a gas-type internal combustion engine 1 having several cylinders 2 (only one of which is indicated), an intake tract 3, an exhaust tract 4, an 15 inlet valve 5, an outlet valve (not shown), an actuator with an adjustment mechanism 6 for discretely adjusting the valve lift of the inlet valve 5, an injection valve 7 for the injection of fuel, a spark plug 8 having an ignition angle adjustment mechanism 9 and a throttle 20 valve 10 in the form of a butterfly valve, which is mounted in the intake tract 3. Further devices required for operating the internal combustion engine 1 which are known to the person skilled in the art are not shown, as they are not necessary to the understanding of the 25 present invention.

The operation of the internal combustion engine 1 is regulated by an electronic operation control unit 11. As indicated by the dashed lines, the operation control unit 30 11 is connected to the inlet valve 5 and/or adjustment mechanism 6 thereof, to the injection valve 7, to the spark plug 8, to the ignition angle adjustment mechanism 9 and to the throttle valve 10 by means of control leads, in order to regulate operation depending on sensor 35 signals. As such a method of regulation is essentially known to the person skilled in the art, it will only be described here to the extent necessary for the

understanding of the method according to the invention for controlling the valve lift of inlet valves.

5 The valve lift of inlet valves 5 in the exemplary embodiment can be adjusted by means of the adjustment mechanism 6 between a low and high valve lift, with high valve lift leading to the relevant cylinders being filled for example 50% more in comparison with low valve lift.

10 It is now assumed that the valve lift of inlet valves 5 is to be switched from the low to high value. At this point, the required torque TQ_{REQ_CLU} delivered by the internal combustion engine 1 to its clutch (not shown) is for example 100 Nm. Furthermore, if $TQ_{kl} = 100$ Nm for the 15 actual clutch torque with a low valve lift, the actual clutch torque with a high valve lift would be $TQ_{gr} = 150$ Nm.

20 The operation control unit 11 now adjusts the valve lift of the inlet valves 5 for half the cylinders, i.e. for two cylinders in the case of a four-cylinder internal combustion engine. If this valve lift adjustment is carried out without an additional regulating control operation, a torque of $(100 \text{ Nm} + 150 \text{ Nm}) / 2 = 125 \text{ Nm}$ is 25 delivered. To avoid this sudden change in torque, in other words to ensure constant torque, the cylinders with high valve lift at least, and if necessary the cylinders with low valve lift as well, are operated at reduced efficiency. This is achieved by adjusting the ignition 30 angle from a base ignition angle toward a later ignition point (thus referred to as ignition angle resetting). Alternatively, as mentioned above, the reduction in efficiency can also be achieved by operating the cylinders with a leaner air/fuel ratio.

35 At the same time, the throttle valve 10 is adjusted in the close direction, in order to reduce the pressure in the intake tract 3 downstream of the throttle valve 10.

The throttle valve 10 of the operation control unit 11 is expediently set at a degree of opening at which a pressure is achieved in the intake tract 3 producing a torque of 100 Nm, provided the valve lift for all 5 cylinders has been set to a high value.

Due to the drop in pressure in the intake tract 3, the torque TQ_{k1} delivered by the cylinders with low valve lift also drops. The difference between the required torque 10 TQ_{REQ_CLU} and torque TQ_{k1} must be taken over by the cylinders with high valve lift. Each of these cylinders must therefore deliver the following additional torque: $(TQ_{REQ_CLU} - TQ_{k1})/\text{number of cylinders}$. For each of these cylinders with a high valve lift, a required torque of 15 $(TQ_{REQ_CLU} + TQ_{REQ_CLU} - TQ_{k1})/\text{number of cylinders}$ is therefore produced.

While the ignition angle adjustment immediately impacts on the combustion in the cylinders after the valve lift 20 adjustment, the change in pressure in the intake tract 3 caused by the adjustment to the throttle valve 10 is only noticeable in the cylinders after a delay. Due to a regulating control by the operation control unit 11, the ignition angles for the relevant cylinders during this 25 time are readjusted toward the base ignition angle. In the present example, the base ignition angle for the relevant cylinders is reached when $TQ_{k1} = 80\text{Nm}$ and $TQ_{gr} = 120\text{ Nm}$.

At this point at the latest, the valve lift for the other 30 half of the cylinders is adjusted to the high value. After this switchover, the cylinders are again operated at reduced efficiency by adjusting the ignition angle (and/or by adjusting the air/fuel ratio). As soon as the pressure in the intake tract 3 has reached the target 35 value, the base ignition angle for the cylinders is again set via a regulating control by the operation control unit 11, so that all cylinders then run again at optimum efficiency.

If the valve lift of the inlet valves 5 is switched from a high to low value, the same measures will be taken correspondingly, but in a reverse sequence. First of all,

5 before any valve lift adjustment, the throttle valve 10 is adjusted in the open direction, and at the same time the ignition angle for the cylinders is adjusted toward a later ignition point, in order to operate the cylinders at reduced efficiency. If the pressure in intake tract 3

10 then reaches a satisfactory value, the valve lift is adjusted to a low value for half the cylinders. The value of the pressure in the intake tract 3, at which the valve lift is adjusted, is selected such that the efficiency of all cylinders after adjusting the valve lift of the first

15 half of the cylinders is close to one. The efficiency of cylinders with high valve lift and if applicable of cylinders with low valve lift then decreases relative to the increasing pressure in the intake tract 3. As soon as this pressure is sufficient to be able to provide the

20 required torque with low valve lift for all cylinders, the valve lift for the second half of the cylinders is switched over to a low value. After this, all cylinders will again run at an efficiency of one.

25 As already mentioned, the reduction in efficiency of the cylinders can also be effected by creating a leaner air/fuel mix or by combining both methods. It should also be noted when adjusting the valve lift, that consecutive combustion cylinders have different valve lifts. In other

30 words, combustion takes place alternately between a cylinder with low valve lift and then a cylinder with high valve lift. This makes it easy to switch over with relatively simple calculation of the corresponding operating parameters.

35 The described valve lift switchover method can also be used for internal combustion engines which have inlet valves enabling multi-stage discrete valve lift

adjustment instead of two-stage adjustment. The described method is also correspondingly suitable for switching over inlet valves for each cylinder individually, with the cylinders being switched over according to their 5 valve lift, e.g. one after the other or consecutively in pairs.

With the method described above to switch over valve lift, it was tacitly assumed that it would be possible to 10 adjust the ignition angle in order to reduce the efficiency of the cylinders, and that this angle would be sufficiently large to avoid a sudden change in torque with the respective valve lift switchover. However, there are also possible operating conditions in which, for a 15 valve lift switchover at neutral torque, an ignition angle adjustment is required which is so large that the minimum ignition angle has to be undershot. In this case, the operation control unit 11 would restrict the ignition angle to the minimum ignition angle, which would in turn 20 cause a sudden change in torque.

It is therefore desirable to identify a criterion for determining whether or not it is possible to switch over valve lift at neutral torque under a specific operating 25 condition (i.e. to switch over valve lift without any sudden change in torque).

Such a criterion is described below, initially for the case in which the inlet valves of a low valve lift (cam 30 lift) are switched over to a high valve lift (cam lift).

The following equation is applicable for the limit of a valve lift switchover process at neutral torque:

$$35 \quad \text{NR_ZYL} * \text{TQI}_{k1_N} * \text{EFF_IGA_BAS}_{k1_N} = \\ \text{NR_ZYL} / 2 * (\text{TQI}_{k1_N} * \text{EFF_IGA_MIN}_{k1_N} + \text{TQI}_{gr_N} * \text{EFF_IGA}_{gr_N}) \\ (1)$$

Where:

NR_ZYL: Number of cylinders

TQI_{k1_N}: Indicated torque of cylinder with low cam lift

TQI_{gr_N}: Indicated torque of cylinder with high cam lift

EFF_IGA_{gr_N}: Efficiency of cylinder with high cam lift dependent on ignition angle

EFF_IGA_BAS_{k1_N}: Efficiency of cylinder with base ignition angle and low cam lift

EFF_IGA_MIN_{k1_N}: Efficiency of cylinder with minimum ignition angle and low cam lift

15 The left-hand side of the equation (1) represents the torque of all cylinders before a valve lift switchover process, with the cylinders being operated at the base ignition angle (i.e. the optimum ignition angle). After adjusting the valve lift of half the cylinders, the same torque is to be produced, which is shown on the right-hand side of the equation (1). The assumed limit state in this equation was that the ignition angle for the non-switched cylinder with low cam lift was adjusted to the minimum ignition angle. The term TQI_{gr_N} *EFF_IGA_{gr_N} indicates the torque which is delivered after the valve lift switchover of cylinders with high cam lift in order to fulfill the equation (1), i.e. in order to enable a switchover process at neutral torque.

30 Equation (1) gives the following for efficiency
EFF_IGA_{gr_N}:

$$\text{EFF_IGA}_{\text{gr_N}} = \frac{(2 * \text{TQI}_{\text{k1_N}} * \text{EFF_IGA_BAS}_{\text{k1_N}} - \text{TQI}_{\text{k1_N}} * \text{EFF_IGA_MIN}_{\text{k1_N}})}{\text{TQI}_{\text{gr_N}}} \quad (2)$$

This is the efficiency of a cylinder with high cam lift dependent on the ignition angle, at which the cylinders

with high cam lift have to operate after the switchover process, in order to avoid a sudden change in torque. If this required efficiency $EFF_IGA_{gr_N}$ is lower than the efficiency $EFF_IGA_MIN_{gr_N}$ for the minimum ignition angle 5 at high cam lift, the ignition angle would be limited to the minimum ignition angle, which would then lead to a sudden positive change in torque.

When operating the internal combustion engine with low 10 valve lift, efficiency $EFF_IGA_{gr_N}$ and efficiency $EFF_IGA_MIN_{gr_N}$ are therefore continually calculated and compared with each other. If the difference between $EFF_IGA_{gr_N}$ and $EFF_IGA_MIN_{gr_N}$ is less than a threshold 15 value, this shows that a valve lift switchover is not possible without a sudden change in torque. A valve lift switchover at this point is therefore expediently omitted. Another option would be to switch over a smaller 20 number of cylinders to the higher valve lift instead of half the cylinders. For example, in an internal combustion engine with six cylinders, it is possible to switch over only two instead of three cylinders, with the necessary ignition angle adjustment being reduced accordingly.

A criterion for the option of a valve lift switchover at 25 neutral torque from high cam lift to low cam lift can be determined as follows. The following equation applies for the limit of a valve lift switchover process at neutral torque:

$$30 \quad NR_ZYL * TQI_{gr_N} * EFF_IGA_MIN_{gr_N} = \\ NR_ZYL / 2 * (TQI_{k1_N} * EFF_IGA_{k1_N} + TQI_{gr_N} * EFF_IGA_MIN_{gr_N}) \\ (3)$$

The left-hand side represents the torque of all cylinders 35 before the switchover process, assuming that the ignition angle has been returned to the minimum ignition angle (and the throttle valve 10 has been adjusted in the open direction to increase pressure in the intake tract). The

right-hand side of the equation (3) represents the sum of the torques, which has to be delivered by the cylinders with low cam lift and the cylinders with high cam lift after the switchover process, in order to avoid a sudden
5 change in torque.

Equation (3) gives the following for efficiency
EFF_IGA_{k1_N}:

10 EFF_IGA_{k1_N} =

$$(2 * TQI_{gr_N} * EFF_IGA_MIN_{gr_N} - TQI_{gr_N} * EFF_IGA_MIN_{gr_N}) / TQI_{k1_N}$$

 (4)

Efficiency EFF_IGA_{k1_N} is the efficiency at which the
15 cylinders with low cam lift would have to operate after the valve lift switchover in order to keep the torque at a constant level.

If efficiency EFF_IGA_{k1_N} is higher than efficiency
20 EFF_IGA_BAS_{k1_N}, a sudden negative change in torque is created. Efficiency EFF_IGA_{k1_N} and efficiency
EFF_IGA_BAS_{k1_N} are therefore continually calculated and compared with each other, to produce a criterion for the option of valve lift switchover at neutral torque. If the
25 difference between EFF_IGA_BAS_{k1_N} and EFF_IGA_{k1_N} is less than a threshold value, there is either no valve lift switchover or a valve lift adjustment takes place for a reduced number of cylinders, in order to avoid a sudden change in torque.

30 The method described above thus provides a reliable criterion for deciding whether a valve lift switchover is permissible from a low to high cam lift as well as from a high to low cam lift.

35 Referring to the flow diagram in Figure 2, an example is described for the method according to the invention for controlling the valve lift of discretely adjustable inlet

valves. It is assumed that the internal combustion engine is running with the inlet valves having low valve lift. Whether a switchover is to be made to high valve lift is therefore continually queried (stage 13).

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If the answer to this query is yes, a check is made to see whether the first half of the cylinders is to be switched over, without creating a sudden change in torque (stage 14). In more detailed terms, a check is made as 10 described above, to see whether the difference between $EFF_IGA_{k1_N}$ and $EFF_IGA_MIN_{gr_N}$ is less than a threshold value. If so, the valve lift for the first half of the cylinders 2 is adjusted as well as the throttle valve 10 as described above (stage 15).

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A check is made at this point to see whether the second half of the cylinders can be switched over (stage 16). For example, as described above, a check is made to see whether the ignition angles for the first half of the 20 cylinders have returned to the base ignition angle. If so, the valve lift for the second half of the cylinders is switched over as described above (stage 17). The valve lift for all cylinders is therefore switched over to high lift.

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If the answer to the query at stage 14 is that it is not possible to switch over the first half of the cylinders at neutral torque, it is then usually possible to switch a smaller number of cylinders over to the higher valve 30 lift at neutral torque. In the example shown in Figure 2, only one cylinder is initially switched over to the high valve lift in this case (stage 18). A check is made at this point using the criterion referred to above, to determine whether the next cylinder can be switched over 35 to high valve lift (stage 19). If so, the second cylinder is switched over to high valve lift (stage 20). This method is continued accordingly, until the last cylinder has been switched over to high valve lift (stage 21).

It is understood that, depending on the number of cylinders in the internal combustion engine, switching over the cylinders in pairs and/or groups can be

5 considered, if it is not possible to switch over half the cylinders at neutral torque. Any corresponding adaptation and/or change to the flow diagram shown in Figure 2 is therefore evident to the person skilled in the art.